November 2011

ENG450

Contaminated Site progress report

Submitted to:

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MURDOCH PERTH WA
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A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering

Due to copy right reasons Figures 6 through to Figures 12 and Appendices A and Appendices B have been removed from this copy.

FINAL REPORT

Brett Bouwer

Executive summary

Figures 6 through to figures 12 and Appendices A and Appendices B have been removed from the public copy due to copy right reasons.

This Final Project Report contains information on the contaminated site Project (ENG450) conducted at Golder Associates, which is located 10km from the CBD in Western Australia. It focuses on the procedures that were conducted for the August quarterly groundwater sampling round, the results obtained from the site investigation and my evaluation of Golders performance in relation to the laws and regulations for contaminated sites, which are required within the scope of the project.

A total of 27 groundwater monitoring locations were sampled as part of the quarterly sampling round over 3 days. A peristaltic pump and low flow purging was the chosen technique for this site. The following is a brief summary of the results obtained.

Field parameters measured at each location were generally within the range observed during previous rounds. Conductivity was lower in MB14B than previously recorded at the site, and measured ORP (Oxidation Reduction Potential) was lower in MB13A and higher in MB20B than previously recorded. The remainder of the field parameters were similar to the May 2011 levels recorded

The assessment of the field and laboratory data indicates that the quality assurance and quality control acceptance criteria for groundwater were met with the exception of RPDs greater than 50% for three of the triplicate samples. Never the less, based on the results of the overall QA/QC programme it is considered that the data has been validated.

The mass flux estimate for tetrabromoethane (TBE) in this quarterly monitoring round is 3.065 kg/year. The mass flux was calculated using the TBE concentrations from MB22A-C, MB48A-C, MB24A-C and MB47A-C. A decrease in TBE mass flux concentrations is noted from the August 2010 monitoring round (3.26 kg/year) to the August 2011 monitoring round.

Overall, the changes to the plume and hydraulics at the site are minor, despite the potential impacts of the changes in pumping regime. It is likely premature to draw any major conclusions based on results from the August monitoring event.

From my own personal research of the literature and time spent at Golder Associates I believe that they have been closely following all the laws, regulations and guidelines required by the DEC and ANZECC. Golder are very keen and eager to adopt new and improved techniques that emerge in order to maintain their reputation and prove the high regard they have for the environment, which is displayed in their company slogan "Engineering Earths Development, Preserving Earths Integrity". The DEC Contaminated Sites Management Series guideline documents are the main source of information for assessment for contaminated sites and throughout my review, Golder have taken on board all the guidelines as well as additional recommendations made by the DEC regarding contaminated sites for the project in which I was involved in.

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TABLES (IN TEXT)

TABLES - INCLUDED IN APPENDIX A (*Appendices A and Appendices B have been removed from the public copy due to copy right reasons)*

FIGURES (*Figures 6 through to figures have been removed from the public copy due to copy right reasons)*

1.0 INTRODUCTION

1.1 Background and project issues

The Site is located approximately 10 km from the Perth Central Business District in WA. The Site consists of an 'L' shaped area of about 0.7 ha and is occupied by three buildings. At present, the Site and surrounding area are zoned for light industrial use and the local Shire has indicated that it is their intent to retain this type of zoning in the foreseeable future.

The site is nominated as a source site within the classification system of the Contaminated Sites Act 2003 (CS Act). Dense Non-Aqueous Phase Liquid (DNAPL) releases have created a dissolved phase contaminant plume migrating with groundwater flow, impacting off-site properties and potentially discharging to an open drain. The principal surface water bodies in the area are the open drain, located approximately 180 m to the west, and the Swan River, located approximately 400 m to the north-west.

The Site was acquired by an organisation in 2000. Prior to that, it is believed that a mineral processing facility operated at the Site from between 1980 and 2000. It is understood that a range of chemicals were used during the operation of this facility, including tetrabromoethane. An inspection by the organisations personnel following the takeover of the Site in 2000 identified the possibility of process-related chemicals in the sub-surface. Subsequent investigations confirmed the existence of specific brominated chemicals in soil and groundwater

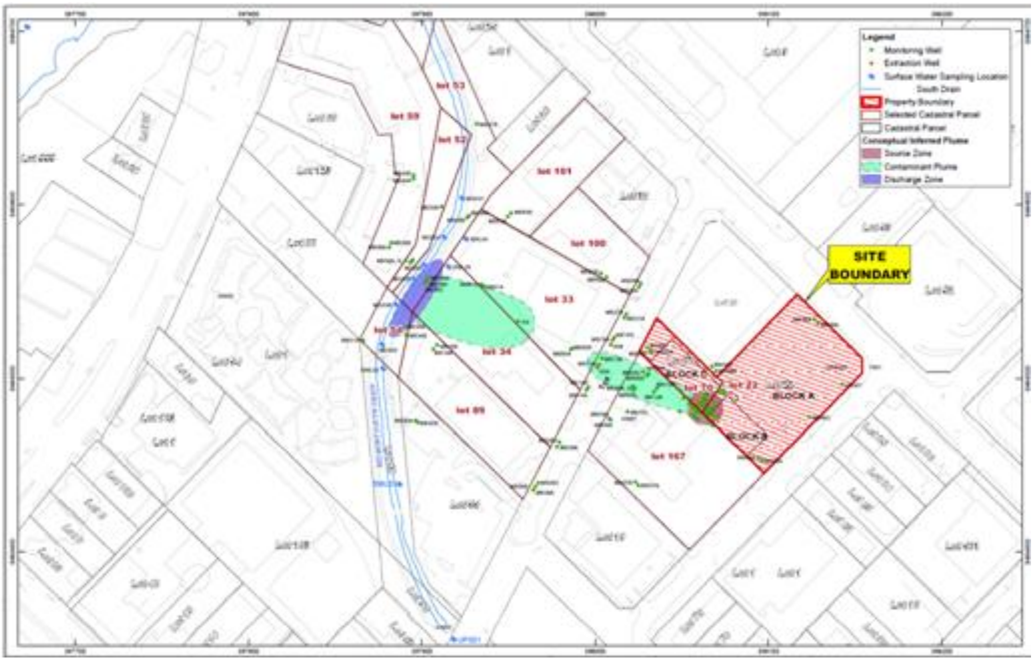


Figure 1. Generic contamination conceptualisation

1.2 Source of waste

The Site was originally developed for use as a mineral processing facility, which operated for approximately 20 years between 1980 and 2000. The facility was primarily used to receive, store and process gravel samples for certain outcomes. This process involved wet, dry and heavy media separation of the gravel samples. The principal chemical used in the heavy media separation process was tetrabromoethane.

The Site was acquired by the current owners, in late 2000. Whilst decommissioning the facility, ruptured pipe work associated with the drainage system was discovered, identifying the possibility of facility-related chemicals in the subsurface. Further investigation confirmed that tetrabromoethane had been released to the subsurface, resulting in the soil and groundwater being contaminated with tetrabromoethane (TBE) and its degradation products tribromoethene or TriBE, dibromoethene or DBE, and vinyl bromide or VB.

1.3 Purpose

1. The project is the continuation of the data collection and analysis through to reporting on the situation at the contamination site 10km from the Perth Business District. The objective of this work is to manage and reduce environmental risks so that the land can be reclassified to "Contaminated – Restricted Use", followed by an application for reclassification to "Remediated for Restricted Use".
2. The project reviews legislation and procedures conducted by Golder for the contaminated site.

1.4 Scope

1. The goal of reclassification with no restrictions on groundwater abstraction will not be immediately achievable. The process for closure of the near source properties is therefore likely to occur in two steps; the first being an application for reclassification to "Contaminated – Restricted Use", followed by an application for reclassification to "Remediated for Restricted Use".

   The scope of my involvement within the overall project will be the collection and analysis of data through to reporting on the current situation at the contamination site 10km from the CBD which will be a step towards achieving the goal of reclassification to "contaminated – Restricted Use".

2. Review all legislation relating to the contaminated site, as well as Golders processes throughout the investigation.

1.5 Objectives

Golder Associates requested that the project meet the following objectives:

- A detailed site visit collecting well samples for the quarterly monitoring round.
- Analysis of the data collected, to identify any significant changes from the previous quarterly reports.
- Identification of any anomalies and reasons they may be present.
- Update all the tables and figure with the new data collected.
- Draw conclusions based on results from the August monitoring event, relating to the contamination plume.
- Report on the findings in relation to the conditions of the site prior to pumping.

Murdoch University required the following objectives:

- Include my own reflections on the work and processes conducted throughout the project.
- Review the legislation involved and review Golders processes throughout a contaminated site investigation.
- Research and review the legislation concerning this project and if the methods used are adequate.

2.0 METHODOLOGY

The primary objective of groundwater quality sampling is to produce groundwater samples that give a good representation of the groundwater in the aquifer. Correct preservation and storage should ensure that the samples will remain representative until analytical determination or measurements are made.

The August 2011 quarterly monitoring round was conducted from 22 to 25 August 2011; additional monitoring was conducted on the 8 September 2011. A total of 27 groundwater monitoring locations were sampled as part of the quarterly sampling round. Sampling locations monitored included the following:

- MB01A & B
- MB09A & B
- MB12B
- MB13B
- MB14B
- MB15B
- MB17A & B
- MB22A, B & C
- MB35A, B&C
- MB36B
- MB47A, B&C
- MB48A, B&C
- MB51B
- MDS01
- MDS02
- MDS03

The following is a detailed description of the procedures that was followed in the sampling process at the contamination site.

2.1 Technique

Low flow purging until chemical equilibrium is reached was the chosen purging technique used for this particular site. This methodology was developed in the 1990s as awareness and understanding for complex hydro-chemical processes that govern the transport of contaminants in the subsurface materials evolved. The primary concern for most contaminated site investigations is characterisation of contaminant flow paths rather than entire aquifers, which can be more accurately assessed through low flow purging techniques compared to high flow purging techniques.

2.2 Procedure

The following procedure was conducted at the contamination site on the 23– 24 August 2011. The site contained 24 individual wells where the following procedure was repeated for each. On the 8 September another 3 wells were sampled, along with three more where the water level was all that was required.

2.2.1 Set-up

The sampling area was to be kept as clean as possible. At the wells that allowed the car to be parked alongside the well a working place was cleaned within the vehicle. Plastic bags were placed on the ground adjacent to the well so that the required equipment could be placed on a clean surface, while ensuring that all the reusable equipment was decontaminated before use.

2.2.2 Low flow purging

Once the work area was set up we needed to measure the depth to the water table below the TOC (top of casing) or nominated reference point with a decontaminated level probe. Once the level of the water had been recorded the setting on the probe is changed and it is lowered 0.1m below the water table. This ensures that when the purging process starts minimal drawdown is achieved and an alarm is activated if the drawdown exceeds 0.1m.

The flow rate was predetermined for the contamination site, based on the hydraulic performance of the wells. The chosen flow rate was from 150 -200 ml per minute.

- Nitrile gloves were worn throughout the purging process (with constant changing to ensure no contamination of samples occurs)
- The peristaltic pump was placed as close as possible to the well, and connected to the well via a new clean piping system for each well.
- We needed to minimise movement of the piping within the well to ensure minimal disturbance of the water column and hence minimise turbidity, volatilisation and oxygenation of the groundwater.
- Then the discharge hose was attached so to flow through the cell where the water quality meter was set up and then into a drum for safe storage and disposal.
- The pump was started at the zero flow position, and then gently increased until the pumping process maintained a water flow at the established rate of 150 – 200ml/min. The flow rate was determined with the timer on the pump and a container of known volume.
- Once the volume of the hose had been purged we recorded the water quality parameters every 5 minutes for a minimum of 30 minutes or until three consecutive readings had been stabilised; defined as below;

Temperature	± 0.5°C
Ph	± 0.1
Redox potential	± 10mv
Dissolved oxygen	± 10%

- If the water level dropped more than the pre set 0.1m, the flow rate had to be reduced and rerecorded and adjusted accordingly for that particular well.
- The final set of field measurements were taken immediately before collecting the samples.
- Three sample jars (one 250ml plastic and two 40ml glass jars) were filled to the specifications on the provided jars.

2.2.3 Collection and field storage of groundwater samples

- We needed to ensure that we put on a new pair of disposable nitrile gloves at the commencement of the sampling procedure.
- We had to make sure we did not handle the insides of the jars or lids
- Each jar was labelled prior to the sample collection. The containers were labelled as follows;

  Golder Associates job number

  Sample identification number

  Date

  Time

  Initials of the sample collector

- The sample jars were filled via the discharge hose at the same or a slower flow rate.
- The 40ml vials needed to be filled so that there were no air bubbles present. The vials were filled capped and then checked for any air bubbles by turning the vial upside down and taping it. If bubbles remain we removed the cap and place more water in the vial.
- Once the samples were taken they were places in a chilled insulated container and wrapped in bubble wrap for extra protection.
- The samples were collected by the laboratory processing company throughout the day. We also delivered some samples to the airport to be transferred to a Melbourne processing facility.

2.2.4 Quality Assurance and Quality Control

- Blanks were carried throughout the sampling process. The blanks were contained in the same volume and type of container as the samples.
- Trip blanks were used to monitor the potential volatile contamination during the transport and storage of the samples. Trip blanks were sent from the laboratory with the empty sample containers and remain with the other samples throughout sampling, storage and transportation.

- Duplicates were taken at a predetermined number of wells instantaneously after the initial samples were taken. Duplicates are taken as a test for precision (repeatability) of sample analysis. Duplicates may either be submitted to the laboratory as 'blind duplicates', with no indication that they are duplicates, or they may be sent to a secondary laboratory as 'split samples', to provide further check on the accuracy of the laboratory analysis. Blind duplicates and split sample processes were both used at the contamination site.

- There was also one triple sample taken where the one laboratory received a blind duplicate and another laboratory received a split sample from the three identical samples.

The following field QA/QC samples were collected:

- Four field duplicates (MB01B, MB17B, MB48C and MB51B)
- One field triplicate (MB17B) and
- Five trip blanks.

Analytical results for the field QA/QC samples are included in table A5. QA/QC criteria for groundwater are summarised in Table 5 in section 3.2, together with an assessment of whether the criteria have been met.

2.3 Well dipping

Prior to the sampling of the wells, a dipping round was conducted which involves a larger number of wells on the site to be dipped with a probe in order to record the water level. This information is located in Appendix A. The RL of Groundwater (m AHD) for particular wells is then used to draw the groundwater contours of the site. The groundwater contours are originally produced by hand with the use of an equation, and then they are sent to a GIS expert to ensure they are accurate. The following equation is used to determine the location and depth of the groundwater between two known points and is what the drawing of the contours is based upon.

Equations

$(A - B) / D = Y$

$L1 - L2 = X$

$H = X / Y$

Where

A = water level of point 1

B = water level of point 2

D = distance between the two locations

L1 = the water level you want

L2 = the water level you know (same as either A or B)

H = the distance from L2 towards the other point that the water level you want is locate

A map of the site with the locations of the wells is used as a template, the RL of groundwater for each of the wells is written on the map and then the previous method is used to hand draw the groundwater contours. This is then sent to the GIS expert who then returns a finalised copy of the groundwater contours, thus indicating the current groundwater flow. Further information is detailed in section 5.0 (Water Levels and Capture Zone) and figure 12 (at the end of the text).

3.0 RESULTS

Groundwater concentration trend plots of principal contaminants for the selected wells are presented in Figure 8 and Figure 9 (at the end of the text). The current and historical mass estimations of TBE in the groundwater are presented in Figure 10 (at the end of the text). Contoured TBE concentrations are presented for the intermediate aquifer in Figure 11(at the end of the text), where the outer contour is plotted utilising the primary remediation criterion for TBE for groundwater.

There were insufficient wells sampled in the August 2011 sampling round to contour the TBE plume in the upper aquifer.

An updated statistical summary of analytical results is presented in Tables 1 to 4 for TBE, dibromoethene (DBE), vinyl bromide (VB) and bromide (Br). Field parameters observed prior to sampling are presented in Table A1. The results of water sampling for Br-VOCs from the upper and intermediate aquifers are presented in Table A2 and Table A3 respectively. The results of QA/QC testing are presented in Table A4, Table A5, Table A6 and Table A7.

3.1 Sampling Results in Historical Context

Table 1: TBE comparison between August 2011 and previous quarterly rounds

	TBE New Minima	TBE New Maxima	Increase in TBE over last sampling round but below previous maxima	Decrease in TBE or no change
Locations	MB35C, MB36B	None	MB09B, MB12B, MB14B, MB15B, MB17A, MB22C, MB35A, MB47A, MB47B, MB47C, MB448B, MB48C	10 out of 27 wells

Table 2: DBE comparison between August 2011 and previous quarterly rounds

	DBE New Minima	DBE New Maxima	Increase in DBE over last sampling round but below previous maxima	Decrease in DBE or no change
Locations	None	MB47C	MB01A, MB09B, MB12B, MB13B, MB14B, MB15B, MB17A, MB22A, MB35C, MB47B, MB47A, MB48B, MB48A, MB48C	8 out of 27 wells

Table 3: VB comparison between August 2011 and previous quarterly rounds

	VB New Minima	VB New Maxima	Increase in VB over last sampling round but below previous maxima	Decrease in VB or no change
Locations	MB09A, MB17A	MB47C	MB09B, MB12B, MB14B, MB17B, MB35C, MB47C, MB48B	16 out of 27 wells (not including multi level wells)

Table 4: Bromide comparison between August 2011 and previous quarterly rounds

	Increase in Bromide over last sampling round	Decrease in Bromide or no change
Locations	MB17A, MB22A, MB35A, MB47A, MB48A, MB09B, MB12B, MB13B, MB14B, MB15B, MB17B, MB222B, MB35B, MB51B	13 out of 27 wells

Field parameters measured at each location were generally within the range observed during previous rounds. Conductivity was lower in MB14B than previously recorded at the site, and measured ORP (Oxidation Reduction Potential) was lower in MB13A and higher in MB20B than previously recorded. The remainder of the field parameters were similar to the May 2011 levels recorded. Ph levels were generally similar to that recorded in August 2009, with the largest Ph difference observed in MB15B (Ph 11.01 in February 2011 compared with a Ph of 7.2 in August 2011). Historically, groundwater Ph at MB15B has ranged from Ph 6.34 to Ph 11.01 (March 2008 – present).

Results from the August quarterly sampling round were also compared to previous quarterly results for each quarter since pumping began in 2007. The moving average (over August and the previous four quarters) of TBE and DBE concentrations for selected wells were plotted since pumping began in 2007. Graphs are included in Appendix B at the rear of this report.

3.2 Quality Assurance and Quality Control

Analytical results for the field QA/QC samples are included in table A5. QA/QC criteria for groundwater are summarised below, together with an assessment of whether the criteria have been met.

The analytical results for quality assurance duplicate samples have been compared to the results of the primary samples. This comparison has been assessed in terms of a Relative Percent Difference (RPD) calculated as:

$$\%RPD = \left|\frac{A - B}{A + B}\right| x200$$

Where:

A is the concentration of an analyte from the initial sample, and

B is the concentration of the same analyte in the duplicate sample.

RPD values can range from 0 to 200, with a value of 0 representing perfect agreement between results, whilst values approaching 200 represent a complete divergence of results. For the purpose of this assessment, Golder considers that an RPD which is less than or equal to 50% represents good correlation between laboratory results.

Where one sample reported a concentration above the detection limit and the duplicate was below laboratory detection limits or vice versa, half the limit of detection has been used to calculate the RPD. Where both analytes reported concentrations below the laboratory detection limit, a nominal RPD value of less than 50% has been assigned.

Table 5: QA/QC Table

Item	Objective	Summary of Results	Compliance
Comparison of field and analytical data	Agreement between visual, olfactory, PID and other field measurements with laboratory results	Wells that exhibited a slight sweet BrVOC odour showed levels of BrVOCs.	Yes
Chain of Custody Records	Completed in full	Completed in full	Yes
Recovery and analysis of rinsate blanks	No contamination of blanks	No rinsate were taken, used a peristaltic pump	Yes

Recovery and analysis of trip blanks	No contamination of blanks	No contamination of blanks	Yes
Recovery and analysis of 5-10% field split duplicate samples	RPDs within +/- 50% for results > 5 × laboratory detection limit (LDL)	Five RPD were above 50%	No
Recovery and analysis of 5% field blind triplicate samples	RPDs within +/- 50% for results > 5 × LDL	Three RPDs were above 50% and >5 x LDL	No-Note 1
NATA-certification and approved analytical methods	Comply with reference	All complied	Yes
Sample preservation and holding times	Comply with reference	Comply with reference	Yes
Analysis of 5% laboratory method blanks	No contamination of blanks	No contamination of blanks	Yes
Analysis of 5% laboratory duplicates	RPDs within ±20% for results > 5 × LDL	Complied	Yes
Analysis of 5% surrogate spike recoveries	Percentage recovery 70-130%	All surrogate spike recoveries were measured within the acceptable limits	Yes

1. *One triplicate sample (MB17B) had a RPD greater than 50% for cis-1, 2-dibromoethene, trans-1, 2-dibromoethene and vinyl bromide and are likely due to Br-VOC degradation during transport.*

The assessment of the field and laboratory data indicates that the QA/QC acceptance criteria for groundwater were met with the exception of RPDs greater than 50% for three triplicate samples. Never the less, based on the results of the overall QA/QC programme, it is considered that the data has been validated.

4.0 PLUME MASS AND FLUX ESTIMATION

The mass of TBE in the plume in August 2011 was calculated using the following methodology. Key monitoring bore locations were selected in the upper and intermediate aquifers where both sufficient and reliable data was available. A corresponding ‘area of influence’ was created for each of the selected bores. This ‘area of influence’ was generally approximated by extending the area for each well half the distance to adjacent wells. The parameters used in this calculation are included in Table A8. A summary of the mass estimates of TBE at each bore and the subsequent total mass of TBE in the plume for each aquifer is presented in Table A9. The total estimated mass of TBE in the plume for each monitoring round is shown in Figure 10. The calculation for estimation of the mass of TBE in each aquifer is presented in the equation below:

Mass TBE (kg) = (1e-6) x Area(m^2) x Thickness(m) x Porosity x Conc.(µg/L)

The mass of TBE in the plume was estimated to be approximately 14 kg in August 2011, with approximately 0.3 kg in the upper aquifer and 13.7 kg in the intermediate aquifer. The estimate is lower than the average calculated in the previous quarterly (32.3 kg). The lower increase in the mass estimation from the previous quarterly can be largely attributed to decreasing concentrations in wells MB01A, MB01B, MB13B, MB17B, MB22B, MB35B and MB51B.

The mass flux estimate for TBE in this quarterly monitoring round is 3.065 kg/year. The mass flux was calculated using the TBE concentrations from MB22A-C, MB48A-C, MB24A-C and MB47A-C. A decrease in TBE mass flux concentrations is noted from the August 2010 monitoring round (3.26 kg/year) to the August 2011 monitoring round. The graph below depicts the concentration trend since August 2010.

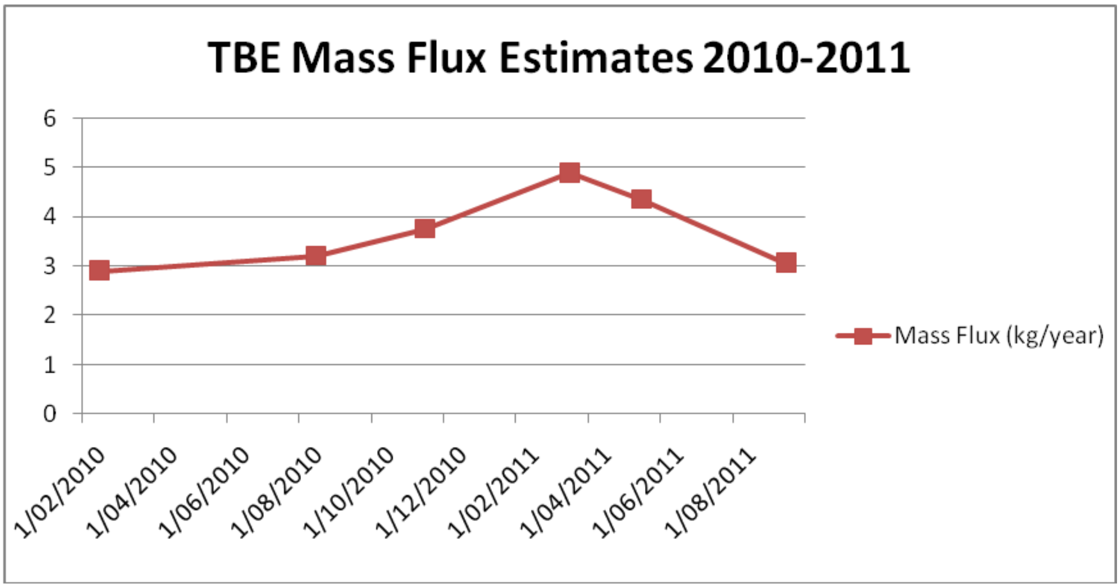


Figure 2. TBE mass flux estimation

5.0 WATER LEVELS AND CAPTURE ZONE

Capture zone prediction of the extraction system is historically based upon water levels collected during the quarterly monitoring events. Figure 12 presents a hydraulic head map for the intermediate aquifer.

6.0 SUMMARY AND RECOMMENDATIONS

Based on the monitoring results, plume mass estimates remain lower than when monitoring began in 2003. The revised plume mass estimates based on reduced plume areas in the intermediate and upper aquifers are lower than those derived in the August 2010 quarterly due to a decrease in concentrations in the wells which dominate the calculation. The estimate is, also, lower than that calculated in the previous May annual monitoring event. Overall, the changes to the plume and hydraulics at the site are minor, despite the potential impacts of the changes in pumping regime. It is likely premature to draw any major conclusions based on results from the August monitoring event.

Overall, large groundwater quality improvements to both the upper and intermediate aquifers have been accomplished on a wide scale since the inception of remediation activities at the site. The average mass estimation over the four quarterly events prior to pumping beginning in October 2007 was 107.7 kg. The average mass estimation of the 5 quarterly events from August 2010 to August 2011 was 28.3 kg, indicating a substantial decrease in mass since pumping commenced.

7.0 LEGISLATION REQUIREMENTS AND LITERATURE REVIEW

When any project is undertaken at Golder it is done so in a staged approach. As quoted by DEC (formally DEP) "In order to obtain the most representative samples and data on a site, the staged approach to contaminated site assessment should be adopted" (DEC 2001). This typically involves four major stages which are shown below in figure 3 literature

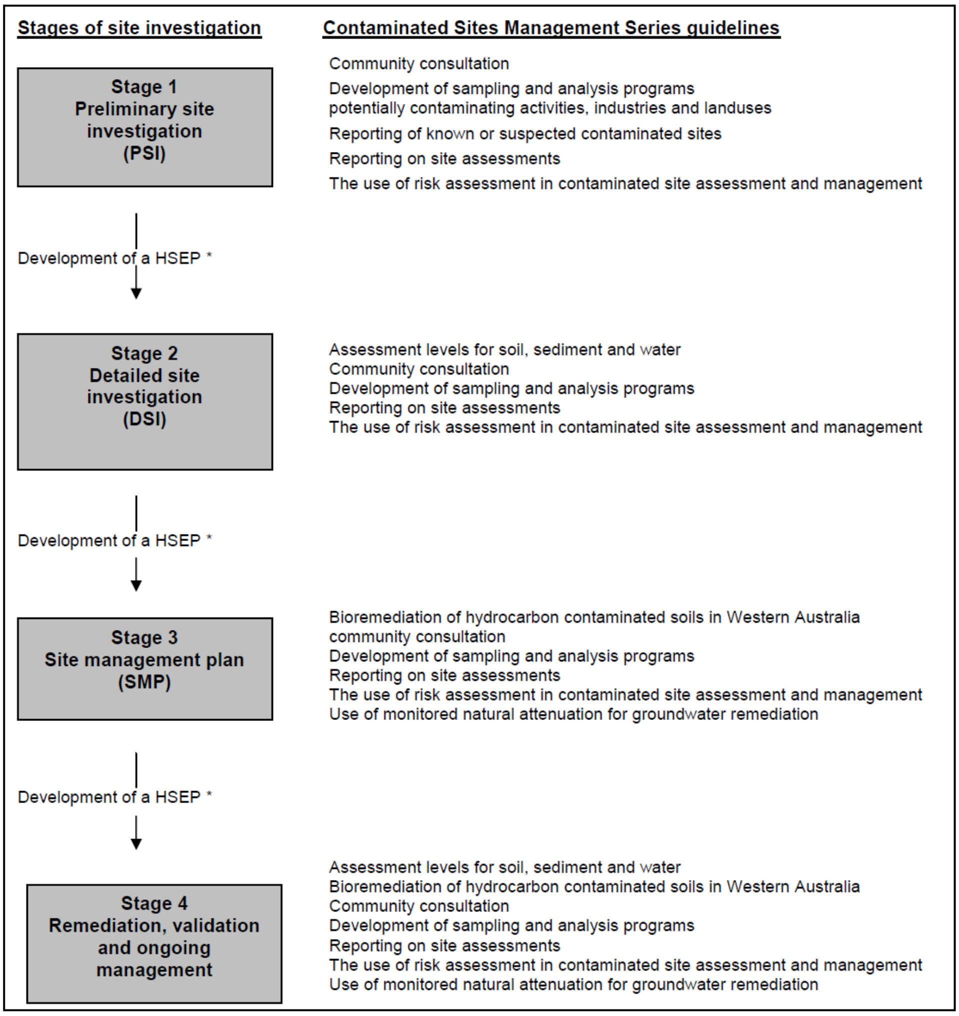


Figure 3. Staged approach to site investigations (DEC 2010)

The flow chart above highlights the appropriate guidelines that should be consulted during each stage of the site investigation and is part of the Contaminated Sites Management Series. The Contaminated Sites Management Series was prepared by the Department of Environment (DoE), now known as the DEC, to provide guidance for requirements under the Contaminated Sites Act, 2003 and to promote a consistent approach to contaminated site assessment and management. One of the main recommendations of the series is the staged approach to site investigation as previously displayed in figure 3.

The object of the *Contaminated Sites Act*, 2003 (the CS Act) is:

> *'…to protect human health, the environment and environmental values by providing for the identification, management and remediation of contaminated sites…'*

The CS Act provides for the reporting of known or suspected contaminated sites (Sections 11 and 12), which would then be classified by the DEC upon consultation with the Department of Health (DoH) and any public authority or person with direct interest in the site (Section 13 CS Act 2003).

In addition to the staged approach outlined above, it is often considered appropriate for large or complex sites to be investigated and reported in stages depending on risk, with higher risk areas prioritised. A staged approach of this nature involves risk ranking of sites with potential contamination issues with subsequent assessment and management based on the potential risks presented.

If appointed, a Contaminated Sites Auditor, accredited under the CS Act, is consulted at each stage leading up to final sign-off following the completion of works at a site. The role of an Auditor is to review documentation for compliance with Guidelines.

The Contaminated Sites Management Series also provides assessment levels that can be compared with analytical sample results to aid the identification of contamination, and to provide an initial assessment of the potential risk the substance may pose to an environment or human health. Where local assessment levels are not available, alternative values may be used as per the DEC guidance.

A human health and ecological risk based approach was used for the development of the assessment levels. Consideration of human health and ecological risk is recommended at each stage of a contaminated site assessment. The main tool for the consideration of risks is the development of a Conceptual Site Model. The Contaminated Sites Management Series provides for the development of risk based site-specific assessment levels, if required.

The following sections of the report will briefly cover stages 1 to 3 and go into more detail on stage 4 as this is the stage the project is currently in and thus I have been involved in.

7.1 Stage 1 – Preliminary Site Investigation

The reason for conducting a preliminary site investigation (PSI) is to uncover past and or present potentially contaminating activities, which may have been taking place on the site or adjoining land. A PSI usually starts with a desk top study and a site walk-over and if required in some circumstances limited sampling may be conducted. The overall outcome of a PSI is to determine if a detailed site investigation is required. The PSI report should contain the following but not be restricted by (DEP 2001);

- should identify all past and present potentially contaminating activities
- should identify potential contamination types

- discuss the site condition
- provide a preliminary assessment of site contamination
- assess the need for further investigations

Golder do not currently have (unable to locate if they do) a PSI for this site. The most likely reason for this is due to the fact that the project started in 2002, and the practices employed by Golder at that time were very different as the regulations and laws that dealt with contaminated sites was very different. I can confirm that for all the more recent projects that Golder undertake a PSI according to the DEC regulations and guidelines is conducted.

7.2 Stage 2 – Detailed Site Investigation

When the PSI is conducted, it determines whether a detailed site investigation is required. The detailed site investigation confirms or dismisses the contamination that was identified during the PSI. This is done via a very comprehensive sampling plan. The purpose of the detailed site investigation is to provide accurate information to be able to describe the extent of the vertical and lateral contamination, on and off site. This should then allow an assessment of the level of risk associated with the environment and human health to be made. Prior to the implementation of the DSI, a sampling analysis program (SAP) is required to set out the objectives of the DSI. This is usually endorsed by an Auditor (if required for the site) prior to the commencement of any intrusive on-site assessments. If gross contamination is encountered during the DSI, further delineation maybe required as additional stages of work. The detailed site investigation is to provide comprehensive information on (DEP 2001):

- Issues raised in the preliminary investigation,
- The type, extent and level of contamination and assess:
  - Contaminant dispersal in air, surface water, groundwater, soil and dust,
  - The potential effects of contaminants on public health, the environment and building structures,
  - Off-site impacts on soil, sediment and biota (where applicable), and
  - The adequacy and completeness of all information available to be used in making decisions on remediation.

Golder Associates have an extensive DSI for the contamination site. All aspects detailed in the DEP 2001DSI check list have been covered. Due to the length of time that the project has been running for and the expectation that it will continue for some time to come, Golder regularly update the DSI in order to ensure that all the information is up to date and relevant to the current operations at the site.

7.3 Stage 3 – Site Management Plan

The development of a site management plan (SMP) documents the type and degree of remediation that will be required for that particular site. This ensures that the site will be suitable for its present uses and any future uses, as well as to protect the surrounding environment. A SMP requires an appropriate management strategy which is environmentally and socially acceptable, is practical and most importantly achieves the required outcomes. The SMP should address the following as stated by (DEP 2001):

- Specific data gaps identified during detailed site investigations;
- Identify the additional information required for the selection and/or design of remedial and/or management options (e.g. active remediation, risk mitigation);
- identify the required baseline data for sites subject to monitored natural attenuation (passive remediation)

Due to the time period that this project has been running and the size of the project Golder have chosen to develop a standalone SMP rather that incorporate it into the DSI. Golder have chosen to include the Sampling Analysis Program (SAP) within the SMP to reduce the total number of documents that need to be up dated and revised on a regular basis. As previously the DEP checklist for SMP has been extensively covered by Golder as well as containing extra information on top of that encouraged by the DEP such as the incorporation of a very extensive SAP. Due to Golders approach to this particular project the Site Management Plan has become a part of stage 4 in a sense, as it is updated accordingly to reflect the remediation and ongoing monitoring.

7.4 Stage 4 – Remediation and ongoing monitoring

When the groundwater is found to be contaminated ongoing monitoring is also required. By having in place an ongoing monitoring program, it will demonstrate the effectiveness of the remediation activities that have been put in place, and it will provide information on whether the objectives of the SMP have been achieved. The DEC highly recommends an ongoing monitoring program as it ensures effective management of the contaminated site.

The DEP 2001 states that the ongoing monitoring program should document the following:

- identify all responsible parties and detail commitments to the monitoring program;
- provide timeframes (e.g. commencement and expected length of program);
- monitoring locations;

- frequency of monitoring;
- methodology of monitoring, including field and laboratory techniques;
- monitoring parameters;
- any pre-determined trigger levels for further action, i.e. to trigger active remediation;
- frequency of reporting; and
- Parties to be reported to (this may include certain community groups).

Stage 4 is the section of the project that I have been directly involved in (ongoing monitoring). As advised by the DEP 2001 contaminated site management series, stage 4 should consult the following guidelines:

- Assessment levels for soil, sediment and water.
- Community consultation
- Development of a sampling analysis program (SAP)
- Reporting on site assessment
- The use of risk assessment in contaminated site assessment and management

All the requirements of the guidelines above have been covered by Golder Associates for this project within the Site Management Plan and the Quarterly Groundwater Sampling Results reports. I have personally revised all the appropriate documents, with the most relevant DEP checklists and to my knowledge Golder have covered every aspect advised by the DEC. The following section of this report will go into more detail about the five guidelines mentioned above.

7.4.1 Assessment levels for soil, sediment and water

The Assessment Levels for Soil, Sediment and Water guideline have been produced by the Department of Environment and Conservation (DEC), formally the Department of Environment (DoE), and previously before that the Department of Environmental Protection (DEP). The 'Assessment Levels for Soil, Sediment and Water guidelines' were produced to provide consultants, government bodies and any other concerned parties with the required information regarding the assessment levels that the DEC and auditors use to determine if a site is considered to be contaminated . It contains information on the classifications of contaminated sites and the subsequent steps that need to be taken.

As stated by the DEC 2010 "*The chemical assessment levels are mostly sourced from the Australian Water Quality Guidelines for Fresh and Marine Water Quality 2000 (ANZECC & ARMCANZ, 2000), the Australian Drinking Water Guidelines (NHMRC & NRMMC, 2004) (ADWG) and the DoH Contaminated Sites Reporting Guideline for Chemicals in Groundwater (DoH, 2006). DEC has adopted microbiological assessment levels from the Australian Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000), Guidelines for Managing Risks in Recreational Water (NHMRC, 2006) the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (EPHC, NRMMC & NHMRC, 2006) (AGWR) and Draft Guidelines for the Use of Recycled Water in Western Australia (DoH, 2009c)*". Therefore the Assessment Levels for Soil, Sediment and Water guidelines provide a very extensive list of all the requirements for different regulatory bodies for many different circumstances.

The assessment levels presented in this guideline are the figures that Golder used in order to classify and produce an appropriate remedial action plan for the specified site. All the data collected during the sampling rounds are constantly cross checked with the appropriate contaminant levels to determine when and if the site could be reclassified. To reduce the chances of human error the software program esDAT allows you to choose which regulatory body your particular site is dealing with and automatically inserts the appropriate values for all the desired chemicals into an excel file and colour codes the results if a guideline value is exceeded. These excel files are then printed, checked and signed off by another Golder employee to ensure all the guidelines have been identified and are correct. This shows how thorough Golder is with all the results, in order to provide the most accurate and precise analysis of the data obtained from the contaminated site.

7.4.2 Community consultation

The investigation, remediation and management of a contaminated site can result in a string of community concerns. The apprehension may be related to either real or apparent environmental and human health impacts related with contamination as well as the environmental effects and inconvenience of the circumstances arising from the remediation and management put in place for that particular site. The DEC view "effective community consultation as a necessary part of the investigation, remediation and management of each contaminated site."

Those in charge of managing the contaminated site are encouraged to carry out the highest level of effective community consultation, opposed to the minimum community consultation approach, to achieve the best possible result for the industry and community. One of the key objectives of the guideline is not to only aid industry in planning and conducting an effective community consultation process that act in accordance with the DEC and other required legislative expectations, but also to enhance the opportunities for the industry and community by working together. Such opportunities that can be gained include:

- Increased acceptance to appropriate proposals
- enhanced decision-making and sustainable outcomes (the community can suggest new ideas and solutions on issues, which may have not been considered by the other parties involved and in some cases can even result in financial savings
- strong positive relationship/partnership
- increased openness and trust amongst the parties involved
- demonstrated dedication to accountability, democracy and transparency
- A shared understanding about the problems and dilemmas involved in the contamination site
- Increased perception of organisations that include the community in the processes.

The community consultation guideline is not regulatory, but sets out the factors that organisations should take into consideration when determining the degree and timing of community consultation and the stakeholders that should be included.

Based upon the recommendation of the community consultation guidelines provided by the DEP Golder identified the principal external stakeholders for the project as:

- Local City Council;
- Surrounding landowners and occupiers;
- Department of Environment and Conservation (and the Department of Health upon referral);
- Swan River Trust
- Water Corporation; and
- Contaminated Sites Auditor.

The contamination site communication with stakeholders, including consultation on decisions concerning investigation, remediation and management, has been co-ordinated by the staff of the organisation that owns the contamination site. A majority of this communication has been face to face and via correspondence.

The input from stakeholders has been considered with respect to the objectives of site activities i.e. some drilling activities were conducted at night to meet surrounding land owners concerns about noise and site access. The communication process at the site has been effective and it is proposed that the management of stakeholders will continue in the same manner i.e. to be managed by the current owner's staff with information supplied into that process by site consultants as needed.

All the information regarding the community consultation process that is in place at the contamination site is located in Golders Site Management Plan report. The site management plan is update on a regular basis as to keep a clear record of the processes and procedure that are currently being employed at that time.

A community consultation program is largely up to the client/organisation that Golder is doing the work for. In my time spent at Golder I have been a part of some other projects where Golder is trailing new approaches (with the approval from the client), such as producing signs that are put up when sampling and site investigations are being conducted to allow passersby to understand what and why Golder is doing/conducting the work at the site, as well as an information letter drop within the local community so that everyone was fully aware of the works that are going to be conducted. This worked very well as the local community felt as if they were being involved and not left out, and in one instance a community member said that he had three bores/wells on his property and that if suitable we would be more than welcome to use them in as extra sampling locations on our sampling rounds. I believe that given the opportunity (by the client) Golder is trying to implement the most effective community consultation process for that given site.

7.4.3 Development of a sampling analysis program

The development of a sampling analysis program guideline extensively covers all the information that should be included within the SAP. The following will briefly cover what should be in a SAP and how well I believe Golder have followed the recommendations of the DEP.

Previous to any sampling and or data collection at a site, a SAP should be produced so to establish the most successful and representative sampling strategies and analysis parameters.
A SAP should document, as a minimum the following:

- The purpose of the sampling program;
- Background information on the site
- The type of samples to be collect and how many;
- Sample patterns;
- A in depth detailed description of the sampling methods to be followed. It should also include information on the sample jars, sampling devices, equipment decontamination methods, handling procedures of samples taken, sample collection information such as depth and methodology, sample identification, preservation procedure, handling and storage details as well as the organisation to be used for sample analysis and chain of custody details;
- The process involved with storing/disposal of sampling/remedial waste for that specific site.
- Requirements of the sample analysis (chemicals that the samples need to be tested for)
- Quality assurance and quality control procedures and methods.

When developing a SAP the following should be taken into consideration:

- Findings of the Preliminary Site Investigation;
- The intention of the SAP;
- The appropriate handling of contaminated material to avoid any further spreading
- Background sampling locations so to provide a base line value and to establish if that particular site may have naturally elevated readings
- Health and safety, a HSEP should be prepared for each site visit
- potential site outcomes (proposed site uses);
- If there are more effective sampling procedures for that given situation at that site
- Proposed disposal method/location of any waste produced from the sampling and remedial works.

Throughout the investigations conducted on a contaminated site, further contamination, new sources of contamination and changes to future development plans often occur. This therefore changes the goals of the SAP, if the goals and objectives of the overall project change then it is important to re-evaluate the sampling analysis program and establish if it still going to provide the required information and outcomes.

For the particular Ground water sampling round undertaken by Golder there was not an individual SAP. However all the required information as stated by the DEC such as the wells that needed to be sampled and the times in which they should be sampled was all incorporated in the Site Management Plan. This was due to the fact that the project is so large the number of reports that need to be regularly updated was kept to a minimum. The methods and techniques employed at the site can be then found in detail in the previous sampling report. This is seen to be adequate for this particular sampling process as it is a very straight forward and simple process. For the same site a SAP has been prepared for a sampling round where the procedures and techniques are more complex and advanced, this was done for the "Water treatment Plant recommissioning sampling and analysis program". This SAP has been developed solely to provide the required information for the site visit commencing in the weeks proceeding 17th October, and following my review of the document I feel that it contains information on all the required areas previously mentioned. I believe Golders decision not to produce a standalone SAP for the groundwater sampling round is a valid one. I was involved in the sampling of the wells at the site and after reading through the previous sampling report and the SMP I had a good understanding on what was required and the processes involved. The fact that I had never undertaken work of this kind before and I felt I had gained what I needed from those two documents makes me feel that the approach to the SAP for this particular site and process was more than adequate.

7.4.4 Reporting on site assessment

The Reporting on site assessment guideline's goal is to set a benchmark for consistent, reliable and accurate reporting of contaminated sites. It also informs consultants, industries and landowners about the information that the Department of Environmental Protection (DEP) requires in order to efficiently assess contaminated sites in Western Australia. Contaminated site reporting is the foundation for the exchange of information to the relevant stakeholders, and therefore a consistent method of reporting is vital. Currently it is difficult to estimate how many contaminated sites there are in Western Australia. This is mostly due to inconsistencies in the classification and documentation of contaminated sites, and the restrictions associated with the current transfer of information. The Reporting on site assessment guideline, in conjunction with the other DEP guidelines, aims to support the development of a more consistent approach for contaminated site assessment as well as the effectiveness of information transfer.

It is this document that introduces the staged approach and the recommendation of following the stages advised by the DEC (PSI, DSI, SMP and remediation an ongoing management). It provides detailed information on the requirements that the DEC require at each stage of the investigation and the information that needs/should be included in each document, as well as which regulations and other documents need to be consulted for particular situations and sites.

Golder bases their approach to contaminated sites on the DEC contaminated site management series. From my time working at Golder every project I have encountered has been operated on in a similar manner, with all 4 stages being implemented or proposed in the future plans for that site.

If there is ever any doubt about what is required for a particular section of an investigation the entire DEC contaminated site management series in on the internal Golder data base.

7.4.5 The use of risk assessment in contaminated site assessment and management

It was produced for the use by environmental consultants and the general community to gain an understanding of the risk associated with contaminated sites and how they should be addressed. Risk assessment involves assessing the severity of the effect due to exposure and the likelihood of that exposure occurring. The risk assessment guideline is a tool that was produced to provide information to make an educated decision about the requirements for managing the contamination site. The main objectives associated with carrying out a risk assessment on a contaminated site are to ensure that the environment and human health is protected, and to ensure that all the necessary resources are allocated in a justifiable manner to guarantee that unacceptable risks are reduced to an acceptable level.

When the risk assessment identifies that there are potentially unacceptable risks, then risk management is used to control and or eliminate the unacceptable risk. The risk assessment guidelines formalise the process of identifying the key problems such as "the nature of the contamination, the potential hazards present, the significance of data gaps, and the level of uncertainty present" (DEC 2006). Factors that are related to the particular site are taken into consideration such as the depth and distribution of the contaminants and the proposed future land uses. Risk management requires a high level of skill and it is therefore recommended that it be conducted by a professional.

The DEC's aim is for contaminated sites to be managed according to the seriousness of the risk or possible risk that the site presents to both humans and the environment. This therefore allows the people that are in charge of the remediation actions for the site a method to prioritise these actions in order to eliminate or diminish the risks presented within a reasonable timeframe. High priority sites are ones that have been identified to pose a current risk to humans and or the environment. High priority sites warrant an immediate implementation of interim management actions.

When a site is found to be contaminated, the DEC require a site specific solution to the problem at hand to reduce the contaminant levels in accordance with the National Environment Protection Measure (NEPM) and the enHealth Guidelines for ecological health risk assessment.

There are a number of guidance documents advised by the DEC for conducting human health and environmental risk assessment in Australia. Risk assessments should conform to the methods set out in the following documents:

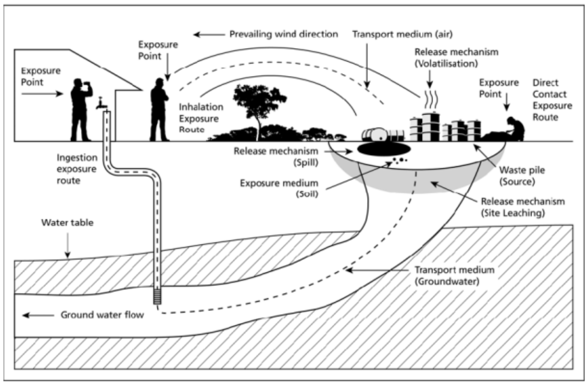
- Australian Drinking Water Guidelines (ADWG)
- ANZECC and ARMCANZ published the Australian and New Zealand Guidelines for Fresh and Marine Water Quality

- Guidelines for Assessing Human Health Risks From Environmental Hazards (enHealth, 2002)
- The National Environment Protection (Assessment of Site Contamination) Measure (NEPC,1999)

As in the overall approach advised by the DEC they recommend adopting the staged approach again for risk assessment, involving the follow steps:

- Tier 1: screening risk assessment
- Tier 2: intermediate risk assessment
- Tier 3: detailed (site-specific) risk assessment.

Within each one of these stages a critical element is the development of a conceptual site model (CSM) that highlights and illustrates the possible pathways where exposure at the site could occur. The initial CSM is then improved as more thorough and accurate information on the site becomes available and the extent of the contamination and all the issues related are better understood. Below in figure 4 is an example a CSM provided by the DEC 2006.



<u>Figure 4 (DEC 2006) conceptual site model</u>

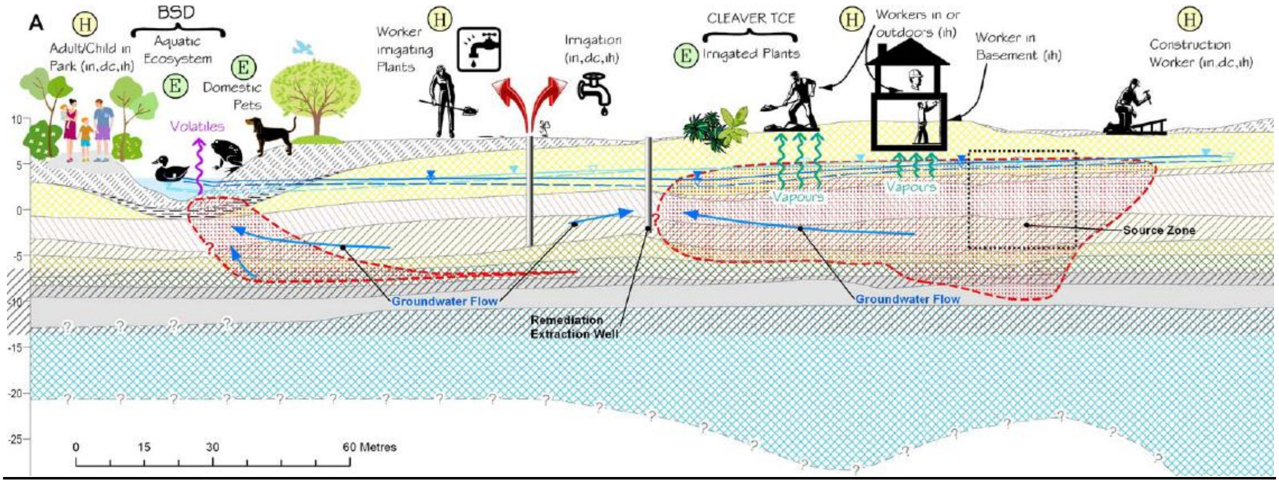


Figure 5 Golder conceptual site model for contaminated site project

This risk assessment approach to prioritising tasks within the project has been adopted by Golder in the decision making processes. For the project in which I was involved the proposal documents clearly stated that they would be using the risk assessment approach for this project. Within the SMP there is a very detailed section within the report on the risk assessment conducted for that site. The Risk Assessment was presented in two parts: a preliminary risk assessment and a detailed risk assessment. The former risk assessment addressed direct exposure pathways, whilst the latter addressed indirect exposure pathways including inhalation of vapours from soil and groundwater contamination. The risk assessments were revised to assess the conceptual site model (figure 5) and the underlying assumptions for the purpose of developing remediation objectives and in light of further data collected for site monitoring and characterisation. Additionally, comments received from the Auditor were considered and incorporated in refinement of the Risk Assessment and the establishment of the remediation criteria. Within the section of the report they go into detail on the following:

- Exposure assessment - identified all the possible following contact pathways
- human health risk assessment
- Ecological Risk Assessments
- Ecotoxicology and bioaccumulation studies
- Receptor Identification - receptors and exposure pathways
- Toxicity and exposure assessment

Golder to my knowledge has adopted the Risk assessment process recommended by the DEC for the overall decision making and planning process for contaminated sites. All the topics and areas of investigation advised by the DEC for risk assessment have been conducted by Golder for this particular project

8.0 LEADING EDGE ADVANCEMENTS

Golder is constantly trying to improve their performance in both the services they supply to their clients as well as the impact they are having on the environment. During my time at Golder I have had the chance to attend weekly meetings and events, in which some new technologies have been discussed and steps put in place to move towards some new leading edge approaches to contaminated sites. One example is a contaminated site located in Italy, where Golder is producing a proposal to use a electrokinetic remediation process. There has been extensive research on this technique and it has proven to be a less intrusive and valid solution for particular situations as presented in the *Journal of Environmental Science and Health, Enhancing Electrokinetic Remediation of Cadmium- Contaminated Soils with Stepwise Moving Anode Method*. This paper discusses a ground-breaking approach by stepwise moving anode towards cathode to enhance the cadmium (Cd) removal from soil during the process of electrokinetic (EK) remediation. As stated in this paper "the basic idea proposed provides a novel and environmental friendly method to enhance the EK remediation of heavy metals contaminated soils". This is the first time that Golder (Perth office) has proposed this process for remediation, proving their drive to be the leading organisation in environmental engineering.

I have also been advised that if appropriate they will employ bioremediation techniques, like those covered in Hearst Communication, Inc (2011) this is a process where naturally occurring or genetically modified microbes are used to clean up the contaminated waste. This process at date is most commonly used for gasoline contamination, studies have shown that rapid microbial degradation of gasoline occurs in the unsaturated zone. As more research is carried out and a greater understanding on all aspects of this unique process is gained, the application and efficiency of bioremediation will grow rapidly. However this particular practice was not a viable option in the given project, due to the nature of the contaminants in the subsurface. I however know from my time working at Golder that they do utilize bioremediation at suitable sites. In due time Im sure there will be breakthroughs within this unique area of study, that it may one day be able to be used on a vast range of contaminants including TBE and its constituents.

9.0 CONCLUSION

Based on the monitoring results, plume mass estimates remain lower than when monitoring began in 2003. The revised plume mass estimates based on reduced plume areas in the intermediate and upper aquifers are lower than those derived in the August 2010 quarterly due to a decrease in concentrations in the wells which dominate the calculation. The estimate is, also, lower than that calculated in the previous May annual monitoring event. Overall, the changes to the plume and hydraulics at the site are minor, despite the potential impacts of the changes in pumping regime. It is likely premature to draw any major conclusions based on results from the August monitoring event.

Overall, large groundwater quality improvements to both the upper and intermediate aquifers have been accomplished on a wide scale since the inception of remediation activities at the site. The average mass estimation over the four quarterly events prior to pumping beginning in October 2007 was 107.7 kg. The average mass estimation of the 5 quarterly events from August 2010 to August 2011 was 28.3 kg, indicating a substantial decrease in mass since pumping commenced.

Golder has heavily adopted the contaminated sites management series as the basis for the procedures employed within the contaminated sites division. The DEC strongly advises adopting the staged approach. This staged approach initially is broken down into 4 stages ; stage 1 the preliminary site investigation (PSI), stage 2 the detailed site investigation (DSI), stage 3 site management plan (SMP) and stage 4 remediation and ongoing monitoring. Each one of these stages is further broken down into specific components that are required in order to gain the full potential from each of the stages within the DEC's contaminated site management series guidelines.

From my time working at Golder Associates on this and other projects, I believe they have all the necessary systems in place to produce a very high level of service to their clients. They adhere to all the laws, regulations and guidelines required by the DEC and are very keen to adopt new and improved techniques to maintain their reputation and become the most respected global engineering and environmental services consulting firm.

10.0 PERSONAL REFLECTION

Before undertaking my internship at Golder Associates I had very little understanding on all aspects of contaminated sites. Since my time at Golder I have gained valuable experience in everything to do with contaminated sites, as well as the general day to day operations within a professional work place. This report only covers one of the many different projects I was able to participate in. I was involved in a variety of different projects and was able to have a different role within each, by actively going on site and gaining hands on experience the processes involved in contaminated site became much clearer. My field work covered a range of processes from slug and bail down testing to well installation and soil core sampling, I was also able to accompany a member from the hydrology department and experience a little of what is involved in their field of word. I took part in a laboratory visit, which was a good experience to understand a little bit about what happens to the samples we send away as well as broadening my industry contacts. I have thoroughly enjoyed my time at Golder Associates and will take away many valuable new skills.

11.0 BIBLIOGRAPHY

Davison, J. (2005). Risk mitigation of genetically modified bacteria and plants designed for bioremediation. *Journal of Industrial Microbiology and Biotechnology, 32* (11), 639-650.

> This paper deals with the potential advantages of bioremediation and phytoremediation by recombinant microbes and plants. It covers many of the potential risks associated with the use of recombinant bacteria and plants for bioremediation. The methods covered within the paper act to prevent the associated risks, in terms of spread and survival in the surrounding environment. It also discusses how genetic technologies could be applied to risk mitigation.

Department of Environment and Conservation. (2006). *The use of risk assessment in contaminated site assessment and management; guidance on the overall approach*. Retrieved from http://www.slp.wa.gov.au.

> The purpose of the use of risk management in contaminated site assessment and management guideline is to outline the approach adopted by DEC. It was produced for the use of environmental consultants and the general community to gain an understanding of the risk associated with contaminated sites and how they should be addressed.

Department of Environment and Conservation. (2010). *Contaminated sites act 2003*. Retrieved from http://www.slp.wa.gov.au . (Accessed 22 August 2011).

> This paper contains the Act providing for the identification, recording, management and remediation of contaminated sites, to consequentially amend certain other Acts and for related purposes.

Department of Environment and Conservation. (2010). *Contaminated Site Management Series; Assessment levels for soil, sediment and water*. Retrieved from http://www.slp.wa.gov.au.

> This paper contains all the generic assessment levels that have been adopted by the Department of Environment and Conservation (DEC). It provides information that helps to determine if further site investigations will be required by providing guidance on the assessment levels. The list of substances that are provided within the document covers the most commonly encountered substances at contaminated site within Western Australia.

Department of Environmental protection. (2001). Contaminated Site Management Series; r*eporting on site assessments.* Retrieved from http://www.slp.wa.gov.au.

This guideline identifies the stages of a contaminated site investigation. The reason for this paper is to provide a standard for practitioners reporting on site assessment, including the investigation, remediation and validation stages. It encourages consistent and accurate reporting by informing practitioners, industry and landowners of the information that they require.

Department of Environmental protection. (2001). *Contaminated Site Management Series: development of sampling and analysis programs.* Retrieved from http://www.slp.wa.gov.au

This guideline supplies the requirements and techniques that should be used when producing a sampling analysis program. This paper also provides a very in depth check list, which list all the information required by the Department of Environmental Protection when reporting on site investigations and remediation validations.

Fennell, D. E., Haggblom, M. M., Zinder, S. H., & Nijenhuis, I. (2005). *Methods for remediating materials contaminated with halogenated aromatic compounds.* Retrieved from http://www.freepatentsonline.com. (Accessed 30 September 2011)

The document covers methods for remediating area that are contaminated with halogenated aromatic compounds. The process described uses *Dehalococcoides ethenogenes strain 195* which decontaminated halogenated compounds by removing at least one halogen group from the compound. With the addition of a halogenated compound into the contaminated site, stimulates the growth of dehalogenating organisms thus in turn enhancing the effectiveness of the bioremediation process. This article will not form the basis of my research; however it will be useful supplementary information for my research as it is the closest information/research related to the halogenated hydrocarbons present at the Perth contaminated site.

Gorelick, M. (1993). *Groundwater contamination: optimal capture and containment*. Florida, USA: Lewis Publishers.

This article provides an overview of the most important considerations when designing a contamination capture system. The main focus of the book is on contaminated aquifers that contain dissolved materials that are used as a primary drinking water source. It covers a range of techniques from the basic such as analytical and graphic solutions to the more complex one such as simulation based optimal design methods. It also covers the practical guidelines for highly complex cases where complete quantitative techniques are not yet available. This article is not the basis of this report however it supplied valuable supplementary information for my research.

Hearst Communication, Inc (2011). ***How Microbes Clean Up Our Environmental Messes.*** **Retrieved from http://www.popularmechanics.com/science/environment/waste/how-microbes-will-clean-up-our-messes. (Accessed 30 September 2011)**

This article gives a brief introduction into the contamination cleanup strategy called bioremediation using naturally occurring or genetically modified microbes to clean up our messes and how this emerging process is gaining steam, as scientists devise new ways to use bugs against mercury, oil spills, radioactive waste and more.

Kaluarachchi, J. J. ***Groundwater contamination by organic pollutants: analysis and remediation*****. Virginia, USA: American Society of Civil Engineers.**

In this article Jagath covers how Nonaqueous –phase liquids (NAPLs) are often encountered or suspected at contaminated sites, particularly at chemical production and industrial manufacturing facilities. They can be a persistent source of groundwater pollution. To select appropriate remedial strategies for NAPL-contaminated sites, it is necessary to understand the phenomena governing NAPL behaviour in the subsurface. The transport of NAPL-associated dissolved constituents in the subsurface is typically controlled by diffusion, volatilization, sorption, desorption, biodegradation, diffusion and hydrodynamic dispersion. The text covers factors that affect modelling of NAPLs in various medium properties. Also covers analytical tools to evaluate various environmental remediation strategies.

Lemming, G., Hauschild, M., & Bjerg, P. (2010). Life cycle assessment of soil and groundwater remediation technologies: literature review. ***The International Journal of Life Cycle Assessment*** **. Doi: 10.1007/s11367-009-0129.**

This journal covers how life cycle assessment is becoming an increasingly more common tool in the support systems for the decision making process in relation to the cleanup of contaminated sites. This study reviews a range of remediation approaches and uses the life cycle assessment to compare the environmental impacts. When remediation of a site is conducted its aim is to reduce the local environmental problem specific to that site, however at the same time the activities aiding in the cleanup effort can cause other environmental effects on a local, regional and even global scale. By using the life cycle assessment different remediation scenarios can be compared against one another in term of their environmental burden.

Lesage, S., & Jackson, R. (1992). *Groundwater contamination and analysis at hazardous waste sites*. New York: M. Dekker.

The paper on groundwater contamination and analysis at hazardous waste sites describes studies done on the fate of toxic chemicals emerging from hazardous waste sites causing contamination the groundwater. The paper presents case studies from the last 30 years in location all over the world including Australia to highlight the different approaches used in different places. It outlines methods of analysis for groundwater sampling conducted at hazardous waste sites, it also covers details on the analytical requirements for regulatory compliance. This paper also examines different data interpretation techniques used in different locations around the world.

Mack, J., Ellerbusch, F., & Librizzi, W. (2003). Characterizing a brownfields recreational reuse scenario using the triad approach: Assunpink Creek Greenways project. *Remediation Journal*, *13,* 41–59. doi: 10.1002/rem.10083.

This article describes an application of the triad approach to redevelopment of an urban greenway in Trenton, New Jersey. Many environmental issues were solved by using the triad approach such as the determination of no further action for several areas of concern and the ability of the detailed site investigation to provide the required information as to allow the city to make important decisions about the cost involved with the remediation activities and property acquisition.

Vangronsveld, J., Herzig, R., Weyens, N., Boulet, J., Adriaensen, K., Ruttens, A., Thewys, T., Vassilev, A., Meers, E., Nehnevajova, E., Lelie, D., & Mench, M. (2009). Phytoremediation of contaminated soils and groundwater: lessons from the field. *Environmental Science and Pollution Research*. Doi: 10.1007/s11356-009-0213-6.

In this paper, the fundamentals to carry out a successful remediation are discussed. Phytoremediation is an environmental remediation tool which is dependent on many factors such as the degree of soil contamination, the accessibility of contaminants for microorganisms and plant consumption and the capability of the plant to absorb, degrade and accumulate the contaminants. Basically the paper provides an overview of a range of field work experiences in Europe relating to the use of plants and related organisms for the remediation of contaminated soil and groundwater. This article will not form the basis of my research; however it will be useful supplementary information for my research as it has given insight into new emerging approaches the contaminated sites.

Woollahra Municipal Council (2004*). Contaminated land reports, Guide for preparing land contamination reports.* **Retrieved from http://www.woollahara.nsw.gov.au.**

This paper provides information on all the various stages within the reporting on contaminated sites. It explains the steps and information that should be presented in each of the reports such as the preliminary site investigation. It states when certain reports are required and references the legislations that are required for that particular situation

Xue J. Chen, Zhe M. Shen, Tao Yuan, Shen S. Zheng, Bing X. Ju, and Wen H. Wang. (2006), Enhancing Electrokinetic Remediation of Cadmium- Contaminated Soils with Stepwise Moving Anode Method. ***Journal of Environmental Science and Health Part A, 41:2517–2530, 2006***

This paper proposes an innovative approach by stepwise moving anode towards the cathode to improve the cadmium reduction from soil during the process of electrokinetic remediation. the idea that is explained in this paper provides an environmentally friendly method to enhance the electrokinetic remediation of heavy metals in contaminated soil

Yaron, B., Dror, I., & Berkowitz, B. (2010). A new perspective. ***Contaminant geochemistry*****.**

Doi:10.1007/s00114-009-0592.

This paper on contaminant geochemistry brings a new point of view on contaminant geochemistry focusing on irreversible changes in the subsurface due to chemical pollution. The paper covers the process governing contaminant-subsurface interactions and how this contamination can cause irreparable effects to the structure and properties of the subsurface.

12.0 APPENDICES

12.1 Appendix A Tables

12.2 Appendix B moving average

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